Summary of SHRP Research and Economic Benefits of

# PAVEMENT MAINTENANCE

RoadSavers

December 1997

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16. Abstract


In 1995, a project was initiated to assess the costs versus benefits of the Strategic Highway Research Program (SHRP). Information was collected from State and local highway agencies on their experiences with the SHRP products, and this information was used as the basis for an economic analysis of the costs and benefits of the program and its products.

This report summarizes the preliminary findings of an economic analysis conducted by the Texas Transportation Institute. It also describes the pavement maintenance technologies developed under SHRP and the experiences of highway agencies that have used them. In addition, it summarizes the objectives of the research conducted under SHRP on pavement maintenance, and outlines the work conducted by the Federal Highway Administration to refine the products and encourage their adoption.


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## INTRODUCTION

The 1984 Strategic Transportation Research Study identified pavement maintenance as one of six priority areas for research and development.[1] As a result, pavement maintenance became one of the key areas in the Strategic Highway Research Program (SHRP).[2] Established by Congress in 1987, SHRP's mission was to increase the durability and safety of our Nation's roads and bridges.

Research conducted under SHRP targeted six areas: pavement maintenance, concrete and structures, long-term pavement performance, asphalt, work zone safety, and snow and ice control. One hundred and thirty products, including new specifications, tests, equipment, and reports, resulted from SHRP research contracts, which expired in March 1993.

In 1995, shortly after SHRP concluded and during the early stages of the Federal Highway Administration's (FHWA) national program to encourage implementation of the SHRP products, the Transportation Research Board (TRB) SHRP Committee suggested that an objective assessment of the program and its products be conducted. The study, which was conducted during 1996 and 1997, was launched and funded by FHWA. Overall direction for the study was provided by FHWA with the help of the SHRP Assessment Steering Group. The assessment project was managed by the transportation technology transfer center at the University of Nevada-Reno (UNR). The technology transfer centers in Florida, Indiana, Minnesota, Pennsylvania, and Texas assisted UNR in collecting information on how State and local highway agencies were using SHRP products. This information was turned over to a team of engineers and economists at the Texas Transportation Institute (TTI) for use in an economic analysis of the costs versus benefits of SHRP and the SHRP products.

This report presents the preliminary findings of the economic analysis conducted by TTI. It describes the objectives and accomplishments of the research conducted under SHRP on pavement maintenance, as well as the products developed from that research. It also summarizes how State and local governments are using those products.

Four other summary reports, describing the results of the benefits-versus-costs analysis of SHRP's asphalt, concrete and structures, snow and ice control, and work zone safety products, are also available.[3–6,*]

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[*] The long-term pavement performance (LTPP) program is only at its midpoint, and thus it is too early to report on the economic benefits of its products.

## BACKGROUND

The $150 million spent on SHRP over 5 years is the largest single expenditure ever devoted to transportation infrastructure research. Product refinements and implementation continue with the support of FHWA, State highway agencies, and industry.

The Intermodal Surface Transportation Efficiency Act of 1991 authorized an additional $108 million for SHRP implementation and for continuation of the long-term pavement performance (LTPP) program. Funding for SHRP came from a set-aside of one-quarter of 1 percent of Federal-aid highway funds apportioned to the States.

SHRP was administered by the National Research Council in cooperation with FHWA and the American Association of State Highway and Transportation Officials (AASHTO). FHWA has taken the lead in helping State and local highway agencies make effective use of SHRP products.

## OBJECTIVES

The United States spends $25 billion annually on pavement maintenance and traffic services for its 4-million-mi (6-million-km) highway system.[7] This expenditure is about 27 percent of the $90 billion spent each year on our highways.

Despite the large amount of money spent on pavement maintenance and the expanding need for highway maintenance, little research and development has been devoted to increasing the effectiveness of preventive maintenance.

The objectives of SHRP pavement maintenance research were to develop:

1. Maintenance management systems to evaluate the cost-effectiveness of preventive maintenance applied to pavements.
2. Equipment, materials, and methods that increase the efficiency and reduce the life-cycle costs of preventive maintenance.

## RESEARCH PROJECTS

The proposed SHRP research on pavement maintenance identified three projects:[2]

1. Quantifying pavement maintenance effectiveness.
2. Measuring systems and instrumentation for evaluating pavement maintenance effectiveness.
3. Improving materials and equipment for pothole repairs and crack repairs.

The results were expected to provide information to help highway agencies to budget for, administer, and allocate maintenance resources. Successful implementation of the research will allow additional miles of roadways to be operated at a higher level of service for the driving public.

## ACCOMPLISHMENTS

SHRP pavement maintenance research and development produced eight products that can be grouped into three areas: routine maintenance, preventive maintenance, and equipment automation. Table 1 lists the products available in each of these areas. A brief summary of the products available from each of these areas is presented below.

### Routine Maintenance

SHRP developed guidelines on routine maintenance and repairs. The guidelines were published in two manuals: *Asphalt Pavement Repair Manual of Practice*[8] and *Concrete Pavement Repair Manual of Practice*.[9] These manuals covered the following maintenance activities:

- Sealing cracks in asphalt pavements.
- Patching potholes with cold mixes and spray injection.
- Resealing joints in concrete.
- Using partial depth patches to repair spalls in concrete pavements.

For each of these maintenance activities, the guidelines address:

- The need for the repair.
- Materials selection.
- Preparation prior to application of the maintenance treatment.
- Application of the treatment.

Development of the manuals involved field research on materials for pothole repair, crack treatment, joint sealing, and spall repair. The research found that proper pothole application techniques resulted in improved performance for a variety of cold-patching materials. The research also found that for crack and joint seals, proper reservoir geometry was important to performance.

### Preventive Maintenance

Three products were developed for preventive maintenance operations:

1. A manual on rating preventive maintenance treatments for asphalt pavements.
2. Specifications for preventive maintenance treatments.
3. The epoxy-core test for void detection in concrete pavements.

*Manual on Rating Preventive Maintenance*

The manual, *Development of a Procedure to Rate the Application of Preventive Maintenance Treatments,*[10] addresses chip seals, crack sealing, slurry seals, and thin hot-mix overlays for asphalt pavements and crack and joint sealing and undersealing for concrete pavements. The rating process allows for a determination of how well the treatment was applied in the field.

*Specifications for Preventive Maintenance*

The specifications for preventive maintenance operations were developed to assist in the LTPP program's Specific Pavement Studies (SPS) experiments on preventive maintenance treatments. The specifications were based on the best information available from State highway agencies, industry, and the academic community. Specifications were developed for crack seals, slurry seals, chip seals, and thin hot-mix asphalt overlays for asphalt pavements and for crack and joint seals and underseals for concrete pavements. The specifications also included requirements for chip spreaders, asphalt distributors, and emulsions.

*Epoxy Core Test for Void Detection*

The epoxy core test was developed to verify the presence and extent of voids under concrete pavements. The test consists of drilling a small hole through the pavement, pouring a low viscosity epoxy into the hole until flow stops, and coring through the epoxy to determine the depth of penetration of the epoxy. The primary use of the test procedure is to validate measurements obtained with nondestructive test methods.

**Equipment Automation**

Four products involved equipment automation. Crack sealing and pothole patching devices were evaluated to help automate maintenance operations. Ground-penetrating radar and the seismic pavement analyzer were studied for use in collecting information to determine when to apply preventive maintenance treatments.

*Robotic Crack Filling Vehicle*

This device was designed to automate crack sealing and filling. Cameras and vision analysis were used to locate the cracks. Data from the cameras and vision analysis were used to direct the crack preparation and sealing process. The device would reduce the number of workers required to seal cracks in traffic lanes, increasing worker safety. Although significant progress was made in developing the device, it was not fully operational at the end of SHRP.

*Robotic Pothole Patching Vehicle*

The purpose of this device was to automate pothole patching to the point where a truck would be driven to a pothole, cameras on board the truck would take a picture of the pothole, vision analysis would be used to determine what needed to be done, and a computer would direct the automated equipment on the truck to prepare, fill, and finish the pothole. Fewer workers would be necessary to fill potholes in traffic lanes, increasing worker safety.

Although there was improvement in the operation of the pothole patching device, it was changed to a manually controlled robotic system instead of a fully computer-controlled device. At the end of the project, it was capable of filling potholes but was similar to other devices available on the commercial market.

*Radar for Pavement Subsurface Condition*

The device was designed to improve both the analysis tools and equipment used to determine the subsurface condition of pavements. The goal was to be able to identify areas of the pavement that might deteriorate in the future so that maintenance could be undertaken to prevent or retard the damage. Considerable effort was expended on developing new antennas for data interpretation. Additional research is needed.

*Seismic Pavement Analyzer*

The device uses seismic principles to measure the properties of existing pavements. Seismic analysis has been available for a number of years but has not been used for routine pavement testing. The device was intended for routine pavement testing to identify areas that are starting to become damaged. This would allow less expensive preventive maintenance treatments to be applied before the pavement deteriorated to the point that more expensive rehabilitation treatments were needed.

The seismic test requires that accelerometers be fastened to the surface of the pavement. As a result, considerable time and effort are needed to conduct the test. In addition, the travel lane has to be closed so that the test can be conducted.

At the end of SHRP, a prototype of the equipment was available. It is ready for complete field testing.

## POST-SHRP ACTIVITIES

The SHRP research on pavement maintenance led to additional research, development, and implementation activities. These activities were sponsored by FHWA and industry. FHWA activities include additional research on pavement maintenance directed toward the evaluation of LTPP SPS experiments (SPS-3 and SPS-4) placed to assess the performance of maintenance treatments. The study addresses the life cycles of various treatments, life-cycle costs, the timing of treatment application, and implementation manuals. Industry activities include the development of robotic pothole patching equipment, radar for detecting pavement subsurface conditions, and seismic pavement analyzers.

Other implementation efforts included two FHWA showcase workshops. One dealt with pothole, crack, spall, and joint seal repairs. The other addressed preventive maintenance operations, including crack, slurry, and chip seals and thin hot-mix overlays for asphalt pavements, and joint and crack seals and underseals for concrete pavements.

Table 1 lists the number of States that in 1994 reported investigating or using SHRP pavement maintenance products. The pavement repair material guidelines, the manual for rating preventive maintenance operations, and the specifications for preventive maintenance operations had received the most use.[11]

## Case Studies

For the purposes of the economic analysis, seven case studies on pavement maintenance were obtained from five States.* Table 2 contains a State-by-State listing of these case studies. The following are short summaries of the products' benefits.

*Ground-Penetrating Radar*

The radar detects unseen problems. Small flaws can be corrected before serious deterioration occurs. Repairs can be made for minimal cost with little inconvenience.

*Proprietary Materials*

A new cold-mix patching material produces more durable pothole repairs than traditional materials. Pothole repairs made with the cold-mix material last two to four times longer than those made with traditional materials.

*Seismic Pavement Analyzer*

Highly accurate and sensitive, the device identifies, measures, and diagnoses early symptoms of conditions that could lead to pavement distress. Early knowledge of subsurface conditions allows timely action to prolong pavement life.

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* FHWA has published 104 RoadSavers case studies, many of which were based on case studies collected for the economic analysis. The RoadSavers case studies are available on the Internet at www.ota.fhwa.dot.gov/roadsvr.

*Spray Injection*

Spray injection provides patching quality equal to that of proprietary pothole mixes. Both methods have life expectancies of about 21 months, compared with 3 months for locally prepared cold mixes.

## ECONOMIC BENEFITS

Because SHRP products developed through pavement maintenance research have not been used extensively, economic benefits were based solely on the implementation of pothole patching techniques and preventive maintenance strategies.[12]

### Pothole Patching

Annual pothole patching costs for State highway agencies in the United States are estimated at $300 million to $400 million.[12] Money spent on pothole repairs at the local level is about twice that amount.[8] SHRP products should greatly reduce these costs.

Hibbs and Shah summarized the cost-effectiveness of four pothole repair techniques: throw-and-roll with local materials, throw-and-roll with proprietary materials, the semi-permanent technique, and the spray injection technique (Table 3).[13] The Texas Transportation Institute's (TTI) research on the economic benefits of SHRP pothole patching products assumed that current practice involves throw-and-roll with local materials or the semipermanent technique. The average cost of using these methods is $\$43/ft^3$ ($\$1.2/m^3$). TTI assumed that use of pothole repair methods recommended by SHRP will cost about $\$10/ft^3$ ($\$0.3/m^3$), which is similar to the cost of throw-and-roll with proprietary materials or the spray injection technique. The cost savings would be about 77 percent.[12] It is unlikely that all public highway agencies will achieve savings of 77 percent. A more conservative estimate of 25 percent was used in the economic analysis.

This 25 percent cost savings, applied to the $350 million average annual expenditure on pothole repairs by State highway agencies and the $725 million average annual expenditure by local agencies, yields a total potential savings of $268 million per year based on full immediate implementation.

Implementation of the SHRP pothole patching methods is likely to be gradual. Highway agencies are expected to implement the technology based on the successes of other agencies. Taking the annual maximum savings amount of $268 million for highway agencies, savings for slow, moderate, and fast implementation scenarios were calculated for 20 years using a 5 percent discount rate (Tables 4, 5, and 6). Each scenario assumes that implementation is slow in the early years and gradually increases over time.

*Slow Implementation*

- Implementation reaches 25 percent after 20 years.
- Estimated highway agency savings: $295 million.

*Moderate Implementation*

- Implementation reaches 50 percent after 20 years.
- Estimated highway agency savings: $566 million.

*Fast Implementation*

- Implementation reaches 100 percent after 20 years.
- Estimated highway agency savings: $1.1 billion.

The cost of SHRP-related pavement maintenance research, development, and implementation was estimated at $45 million over 20 years.[12] If annual net savings are derived only from pothole patching based on the implementation scenarios given above, the expected benefits outweigh the costs by a range of between 6:1 and 24:1. One dollar of research will return about $6 to $24 to highway agencies (Table 10). User cost savings associated with a reduction in traffic delays as a result of pothole repairs were not considered in this analysis.

**Preventive Maintenance**

The condition and remaining service life of a pavement can be improved with the timely application of appropriate preventive maintenance treatments. Based on practices recommended by the SHRP research, the average asphalt-paved highway would receive a preventive maintenance treatment after 7 years of service. A second preventive maintenance treatment would be applied after 14 years of service, and a hot-mix overlay would be scheduled after 19 years of service.

Current practice is to apply preventive maintenance treatments later in a pavement's life cycle. For example, a preventive maintenance treatment might be applied after 10 years of service. The pavement would then require a hot-mix overlay after 15 years of service.

A 40-year life cycle and 5 percent discount rate were used to calculate cost comparisons between the two practices described above. The cost comparison assumed current pavement serviceability indexes and appropriate highway mileage and numbers of lanes. Annual traffic growth rates of 2 percent were assumed in conjunction with prorated salvage values based on years of remaining pavement life.[12]

Highway agency cost increases incurred from more frequent application of preventive maintenance treatments were offset by a reduction in required overlays. User cost savings resulted from a reduction in delays and vehicle operating costs.

Economic benefits were calculated only for the use of slurry and chip seal treatments.[12] Based on 700,000 mi (1 million km) of asphalt pavement, the potential annual cost savings are $1.16 billion for State highway agencies and $1.89 billion for users, for a total savings of $3.05 billion annually.[12]

Improved preventive maintenance strategies will not be immediately implemented, nor will they be implemented by all highway agencies. Taking the maximum annual savings of $3.05 billion, savings for slow, moderate, and fast implementation scenarios were calculated using a 5 percent discount rate (Tables 7, 8, and 9). Each scenario assumes that implementation is slow in early years and gradually increases over time.

*Slow Implementation*

- Implementation reaches 25 percent after 20 years.
- Estimated State highway agency savings: $1.3 billion.
- Estimated user savings: $2.1 billion.
- Estimated State highway agency and user savings: $3.4 billion.

*Moderate Implementation*

- Implementation reaches 50 percent after 20 years.
- Estimated State highway agency savings: $2.4 billion.
- Estimated user savings: $4.0 billion.
- Estimated State highway agency and user savings: $6.4 billion.

*Fast Implementation*

- Implementation reaches 100 percent after 20 years.
- Estimated State highway agency savings: $4.8 billion.
- Estimated user savings: $7.8 billion.
- Estimated State highway agency and user savings: $12.6 billion.

The cost of SHRP-related pavement maintenance research, development, and implementation was estimated at $45 million over 20 years.[12] If annual net savings are derived only from the use of two preventive maintenance treatments based on the implementation scenarios given above, benefit-cost ratios ranging from 76 to 280 are expected. One dollar spent will return $76 to $280 to State highway agencies and users. (Table 10).

If the cost savings from the SHRP pothole repair methods and preventive maintenance techniques are combined, public highway agencies can expect a return of about $36 at a slow implementation rate, about $67 at a moderate implementation rate, and approximately $131 at a fast implementation rate for each dollar spent on research, development, and implementation. Cost savings to users would be $47, $89, and $173 for slow, moderate, and fast implementation rates respectively. Estimated agency and user savings combined are expected to range from $82 to $304.

**SUMMARY**

It is more important than ever to use limited maintenance budgets wisely, but information about the comparative cost savings of various pavement maintenance technologies has been lacking. SHRP's evaluation of the performance of maintenance materials, methods, and equipment developed much-needed criteria for the cost-effective use of pavement maintenance techniques.

SHRP research that assessed pothole patching and preventive maintenance provided several implementable techniques that can reduce State highway agency costs. Agencies can use the results to determine how much to budget for pothole repairs and preventive maintenance, to select the most effective maintenance technique for a particular project, and to decide the best time to schedule the work.

The use of ground-penetrating radar and the seismic pavement analyzer will result in additional benefits for highway agencies. However, it is not yet possible to estimate the costs-versus-benefits of these two technologies.

## REFERENCES


1. *America's Highways: Accelerating the Search for Innovation.* Special Report 202. Washington, D.C., Transportation Research Board, 1984.
2. *Strategic Highway Research Program: Research Plans.* NCHRP Project 20-20. Washington, D.C., Transportation Research Board, 1986.
3. *Summary of SHRP Research and Economic Benefits of Asphalt.* Publication No. FHWA-SA-98-012. Washington, D.C., Federal Highway Administration, U.S. Department of Transportation, 1997.
4. *Summary of SHRP Research and Economic Benefits of Concrete and Structures.* Publication No. FHWA-SA-98-013. Washington, D.C., Federal Highway Administration, U.S. Department of Transportation, 1997.
5. *Summary of SHRP Research and Economic Benefits of Snow and Ice Control.* Publication No. FHWA-SA-98-015. Washington, D.C., Federal Highway Administration, U.S. Department of Transportation, 1997.
6. *Summary of SHRP Research and Economic Benefits of Work Zone Safety.* Publication No. FHWA-SA-98-016. Washington, D.C., Federal Highway Administration, U.S. Department of Transportation, 1997.
7. *Highway Statistics 1994.* Publication No. FHWA-PL-95-042. Washington, D.C., Federal Highway Administration, U.S. Department of Transportation, 1995.
8. *Asphalt Pavement Repair Manual of Practice.* Publication No. SHRP-H-384. Washington, D.C., Strategic Highway Research Program, National Research Council, 1993.
9. *Concrete Pavement Repair Manual of Practice.* Publication No. SHRP-H-349. Washington, D.C., Strategic Highway Research Program, National Research Council, 1993.
10. *Development of a Procedure to Rate the Application of Preventive Maintenance Treatments.* Publication No. SHRP-H-322. Washington, D.C., Strategic Highway Research Program, National Research Council, 1993.
11. Highway Operations Technical Working Group, Federal Highway Administration. August 24-25, 1994, meeting in Arlington, Virginia.
12. *Economic Benefits of SHRP Research.* Publication No. FHWA-SA-98-017. Washington, D.C., Federal Highway Administration, U.S. Department of Transportation, 1997.
13. Hibbs, John and Shashikant Shah, "Potholes: The Great U.S. Depression of 1994," *Country Roads and City Streets,* Vol. 10, No. 2, August, 1995, pp. 9-14.

## Table 1. Use of Pavement Maintenance Products

| Product Area | Product Number and Title | | Number of States Investigating or Using SHRP Technology* | |
|---|---|---|---|---|
| | | | Investigating | Using |
| Routine Maintenance | 3003 | Pavement Repair Materials Guidelines | 13 | 7 |
| Preventive Maintenance | 3033 | Manual on Rating Preventive Maintenance | 9 | 6 |
| | 3034 | Specifications for Preventive Maintenance | 9 | 4 |
| | 3035 | Epoxy Core Test for Void Detection | 1 | 0 |
| Equipment Automation | 3004 | Robotic Crack-Filling Vehicles | 3 | 0 |
| | 3005 | Robotic Pothole Patching Vehicle | 3 | 1 |
| | 3018 | Radar for Pavement Subsurface Conditions | 7 | 1 |
| | 3019 | Seismic Pavement Analyzer Method | 5 | 1 |

* Developed from Highway Operations Technical Working Group, Summary Report of August 24 - 25, 1994, meeting in Crystal City, Virginia.

## Table 2. Preventive Maintenance Case Studies

| State | Case Study Title |
|---|---|
| Alaska | Pothole Patches Hold Up Better with Custom Mix |
| California | A Quick Fix for Potholes |
| Colorado | Spray-Injection Improves Pothole Repairs |
| Florida | Rapid Method for Detecting Subsurface Problems |
| | Testing Method Proves Effective Management Tool |
| South Carolina | South Carolina Makes Fast Work of Pothole Repair |
| Texas | New Technology Detects Unseen Pavement Problems |

**Table 3. Cost-Effectiveness and Other Data on Pothole Patching**

| | Material Type/Procedure | | | |
|---|---|---|---|---|
| | Local/ Throw-and-Roll | Proprietary/ Throw-and-Roll | Local/ Semipermanent | Spray Injection/ Spray Injection |
| Material, $/ton | 20 | 85 | 20 | 0 |
| Crew, $/day | 300 | 300 | 600 | 0 |
| Traffic, $/day | 250 | 250 | 250 | 250 |
| Equipment, $/day | 80 | 80 | 130 | 930 |
| Productivity, tons/day | 4.0 | 4.0 | 1.5 | 4.0 |
| Tons Required | 200 | 200 | 75 | 200 |
| Patch Life, months | 3 | 21 | 12 | 21 |
| 5-Year Cost, $ | 710,000 | 139,000 | 252,000 | 168,570 |
| Cost Effectiveness, $/ft$^3$ | 44 | 9 | 42 | 11 |

**Table 4. Total Pothole Cost Savings with a Slow Implementation Scenario**

| Year | Implementation Rate (Percent) | Discounted Agency Savings (Million $) |
|---|---|---|
| 1 | 1.0 | 2.68 |
| 2 | 1.3 | 3.32 |
| 3 | 1.8 | 4.38 |
| 4 | 2.4 | 5.56 |
| 5 | 3.1 | 6.84 |
| 6 | 4.0 | 8.40 |
| 7 | 4.9 | 9.80 |
| 8 | 5.9 | 11.24 |
| 9 | 7.1 | 12.88 |
| 10 | 8.3 | 14.34 |
| 11 | 9.6 | 15.79 |
| 12 | 11.0 | 17.24 |
| 13 | 12.5 | 18.65 |
| 14 | 14.0 | 19.90 |
| 15 | 15.7 | 21.25 |
| 16 | 17.4 | 22.43 |
| 17 | 19.2 | 23.57 |
| 18 | 21.0 | 24.55 |
| 19 | 23.0 | 25.61 |
| 20 | 25.0 | 26.51 |
| 20-Year Total | | 294.94 |
| Equiv. Ann. Total | | 23.67 |

**Table 5. Total Pothole Cost Savings with a Moderate Implementation Scenario**

| Year | Implementation Rate (Percent) | Discounted Agency Savings (Million $) |
|---|---|---|
| 1 | 1.0 | 2.68 |
| 2 | 1.7 | 4.34 |
| 3 | 2.7 | 6.56 |
| 4 | 3.9 | 9.03 |
| 5 | 5.4 | 11.91 |
| 6 | 7.1 | 14.91 |
| 7 | 9.0 | 18.00 |
| 8 | 11.1 | 21.14 |
| 9 | 13.4 | 24.31 |
| 10 | 15.9 | 27.47 |
| 11 | 18.5 | 30.44 |
| 12 | 21.4 | 33.53 |
| 13 | 24.4 | 36.41 |
| 14 | 27.6 | 39.23 |
| 15 | 30.9 | 41.83 |
| 16 | 34.4 | 44.35 |
| 17 | 38.1 | 46.78 |
| 18 | 41.9 | 48.99 |
| 19 | 45.9 | 51.11 |
| 20 | 50.0 | 53.03 |
| 20-Year Total | | 566.05 |
| Equiv. Ann. Total | | 45.42 |

**Table 6. Total Pothole Cost Savings with a Fast Implementation Scenario**

| Year | Implementation Rate (Percent) | Discounted Agency Savings (Million $) |
|---|---|---|
| 1 | 1.0 | 2.68 |
| 2 | 2.4 | 6.13 |
| 3 | 4.3 | 10.45 |
| 4 | 6.8 | 15.74 |
| 5 | 9.8 | 21.61 |
| 6 | 13.3 | 27.93 |
| 7 | 17.1 | 34.20 |
| 8 | 21.4 | 40.76 |
| 9 | 26.0 | 47.16 |
| 10 | 31.0 | 53.55 |
| 11 | 36.4 | 59.89 |
| 12 | 42.2 | 66.12 |
| 13 | 48.3 | 72.08 |
| 14 | 54.7 | 77.74 |
| 15 | 61.5 | 83.25 |
| 16 | 68.6 | 88.43 |
| 17 | 76.0 | 93.31 |
| 18 | 83.7 | 97.87 |
| 19 | 91.7 | 102.12 |
| 20 | 100.0 | 106.06 |
| 20-Year Total | | 1,107.08 |
| Equiv. Ann. Total | | 88.83 |

**Table 7. Total Maintenance Cost Savings with a Slow Implementation Scenario**

| Year | Implementation Rate (Percent) | Discounted Agency Savings (Million $) | Discounted Motorist Savings (Million $) | Total Discounted Savings (Million $) |
|---|---|---|---|---|
| 1 | 1.0 | 11.60 | 18.92 | 30.52 |
| 2 | 1.3 | 14.37 | 23.43 | 37.80 |
| 3 | 1.8 | 18.95 | 30.90 | 49.85 |
| 4 | 2.4 | 24.06 | 39.23 | 63.29 |
| 5 | 3.1 | 29.60 | 48.26 | 77.86 |
| 6 | 4.0 | 36.37 | 59.31 | 95.68 |
| 7 | 4.9 | 42.43 | 69.19 | 111.62 |
| 8 | 5.9 | 48.66 | 79.35 | 128.01 |
| 9 | 7.1 | 55.77 | 90.94 | 146.71 |
| 10 | 8.3 | 62.09 | 101.24 | 163.33 |
| 11 | 9.6 | 68.39 | 111.53 | 179.92 |
| 12 | 11.0 | 74.63 | 121.71 | 196.34 |
| 13 | 12.5 | 80.77 | 131.72 | 212.49 |
| 14 | 14.0 | 86.16 | 140.50 | 226.66 |
| 15 | 15.7 | 92.02 | 150.05 | 242.07 |
| 16 | 17.4 | 97.13 | 158.38 | 255.51 |
| 17 | 19.2 | 102.07 | 166.44 | 268.51 |
| 18 | 21.0 | 106.32 | 173.38 | 279.70 |
| 19 | 23.0 | 110.90 | 180.85 | 291.75 |
| 20 | 25.0 | 114.81 | 187.22 | 302.03 |
| 20-Year Total | | 1,277.10 | 2,082.55 | 3,359.65 |
| Equiv. Ann. Total | | 102.48 | 167.11 | 269.59 |

**Table 8. Total Maintenance Cost Savings with a Moderate Implementation Scenario**

| Year | Implementation Rate (Percent) | Discounted Agency Savings (Million $) | Discounted Motorist Savings (Million $) | Total Discounted Savings (Million $) |
|---|---|---|---|---|
| 1 | 1.0 | 11.60 | 18.92 | 30.52 |
| 2 | 1.7 | 18.79 | 30.64 | 49.43 |
| 3 | 2.7 | 28.42 | 46.34 | 74.76 |
| 4 | 3.9 | 39.10 | 63.75 | 102.85 |
| 5 | 5.4 | 51.55 | 84.07 | 135.62 |
| 6 | 7.1 | 64.56 | 105.27 | 169.83 |
| 7 | 9.0 | 77.93 | 127.09 | 205.02 |
| 8 | 11.1 | 91.54 | 149.28 | 240.82 |
| 9 | 13.4 | 105.25 | 171.63 | 276.88 |
| 10 | 15.9 | 118.94 | 193.95 | 312.89 |
| 11 | 18.5 | 131.80 | 214.92 | 346.72 |
| 12 | 21.4 | 145.20 | 236.77 | 381.97 |
| 13 | 24.4 | 157.67 | 257.11 | 414.78 |
| 14 | 27.6 | 169.85 | 276.98 | 446.83 |
| 15 | 30.9 | 181.11 | 295.33 | 476.44 |
| 16 | 34.4 | 192.02 | 313.12 | 505.14 |
| 17 | 38.1 | 202.55 | 330.29 | 532.84 |
| 18 | 41.9 | 212.14 | 345.93 | 558.07 |
| 19 | 45.9 | 221.33 | 360.91 | 582.24 |
| 20 | 50.0 | 229.61 | 374.43 | 604.04 |
| 20-Year Total | | 2,450.96 | 3,996.73 | 6,447.69 |
| Equiv. Ann. Total | | 196.67 | 320.71 | 517.38 |

**Table 9. Total Maintenance Cost Savings with a Fast Implementation Scenario**

| Year | Implementation Rate (Percent) | Discounted Agency Savings (Million $) | Discounted Motorist Savings (Million $) | Total Discounted Savings (Million $) |
|---|---|---|---|---|
| 1 | 1.0 | 11.60 | 18.92 | 30.52 |
| 2 | 2.4 | 26.52 | 43.25 | 69.77 |
| 3 | 4.3 | 45.26 | 73.81 | 119.07 |
| 4 | 6.8 | 68.17 | 111.16 | 179.33 |
| 5 | 9.8 | 93.56 | 152.57 | 246.13 |
| 6 | 13.3 | 120.93 | 197.20 | 318.13 |
| 7 | 17.1 | 148.08 | 241.47 | 389.55 |
| 8 | 21.4 | 176.49 | 287.80 | 464.29 |
| 9 | 26.0 | 204.21 | 333.01 | 537.22 |
| 10 | 31.0 | 231.89 | 378.14 | 610.03 |
| 11 | 36.4 | 259.32 | 422.87 | 682.19 |
| 12 | 42.2 | 286.32 | 466.90 | 753.22 |
| 13 | 48.3 | 312.11 | 508.95 | 821.06 |
| 14 | 54.7 | 336.63 | 548.94 | 885.57 |
| 15 | 61.5 | 360.45 | 587.79 | 948.24 |
| 16 | 68.6 | 382.92 | 624.43 | 1,007.35 |
| 17 | 76.0 | 404.03 | 658.84 | 1,062.87 |
| 18 | 83.7 | 423.77 | 691.04 | 1,114.81 |
| 19 | 91.7 | 442.17 | 721.04 | 1,163.21 |
| 20 | 100.0 | 459.23 | 748.86 | 1,208.09 |
| 20-Year Total | | 4,793.66 | 7,816.99 | 12,610.65 |
| Equiv. Ann. Tot. | | 384.66 | 627.26 | 1,011.92 |

**Table 10. Twenty-Year Cost Savings (Billion $) and Cost-Benefit Ratio* for SHRP Pavement Maintenance Research**

| | | Implementation Rate | | | | | |
|---|---|---|---|---|---|---|---|
| | | Slow | | Moderate | | Fast | |
| Basis of Cost | | Savings (Billion $) | Ratio+ | Savings (Billion $) | Ratio+ | Savings (Billion $) | Ratio+ |
| Agency | Pothole Repair | 0.3 | 6.6 | 0.6 | 13 | 1.1 | 24 |
| | Preventive Maintenance | 1.3 | 29 | 2.4 | 53 | 4.8 | 107 |
| | Subtotal | 1.6 | 36 | 3.0 | 67 | 5.9 | 131 |
| User | Preventive Maintenance | 2.1 | 47 | 4.0 | 89 | 7.8 | 173 |
| Agency and User | Pothole Repair | 0.3 | 6.6 | 0.6 | 13 | 1.1 | 24 |
| | Preventive Maintenance | 3.4 | 76 | 6.4 | 142 | 12.6 | 280 |
| | Subtotal | 3.7 | 83 | 7.0 | 156 | 13.7 | 304 |

* Based on estimated 20-year research, development, and implementation cost of $45 million.

+ Totals may not add up because of rounding.

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